THERMAL METAMORPHISM

in the

ALBION BASIN

of

LITTLE COTTONWOOD CANYON

UTAH

SENIOR THESIS

by

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Introduction

In this paper the effects of thermal metamorphism and metasomatism in three different lithologies will be reported. The three lithologies occur together, cut by an intrusive body and will enable similarities and differences that take place under similar metamorphic conditions, to be compared. These rocks will be categorized in order to make correlations with metamorphic facies. Estimates as to the temperatures involved in this case will be made, and the minerals which are the result of metasomatism will be identified.

The Wasatch Mountains extend from central Utah northward into Idaho. They represent the eastern limit of the Basin and Range Province. On their eastern side, they are indefinitely defined, as they grade into the upland region of the Wyoming Basin and into the Colorado Plateau at the southern extreme. Exposures of sedimentary rock of Precambrian to Jurassic age are found and are cut by Cretaceous and Tertiary stocks and dikes in north central Utah. The Precambrian rocks are represented by white, red or purplish quartzites and a few dark argillites (Calkans 1943). Lying unconformably on them is a Cambrian tillite. This in turn is overlain unconformably by the Tintic Quartzite, whose purplish quartz grains suggest the Precambrian quartzite as a source. Next is a conformable formation of shale, the Ophir Shale. It consists of three members, the lowest and the highest members being shales, and the middle member a limestone. Conformable on the Ophir Shale is the Maxfield Limestone which is a sequence of alternating limestones and dolomites. They are coarse-grained and fossiliferous. Unconformably above the Maxfield Limestone is a body of dolomite and limestone of Middle Devonian age which has been named the Jefferson Formation. Above this are rocks of Mississippian age which include the

Madison Limestone, the Deseret Limestone and, finally, the Humbug Formation. The Humbug Formation is mostly black chert-bearing limestone and some calcareous sandstones. Unconformably above this is the Pennsylvanian Morgan Formation which is mostly limeston. A fine-grained quartzite, the Weber Quartzite is also Pennsylvanian. The Park City Formation is conformable to the Weber, the lower part being Pennsylvanian and the upper part Permian. Triassic rocks lie unconformably over the Park City Formation; red and green thin-bedded shales of the Woodside Shale are overlain by the Thaynes Formation of limestone with some sandstone and shale. The Ankarah Shale of Jurassic age lies above the Thaynes. A unit of Jurassic sandstone and inter-bedded red shale, the Nugget Sandstone, caps the sedimentary section. (Table I)

In north-central Utah, where the Uinta Mountains intersect with the Wasatch Mountains, folding uplift and faulting during Cretaceous and Triassic times resulted from orogenesis. Intrusive bodies of this age are now exposed in the area. Compositional differences in local intrusions suggest different periods of intrusion by a differentiating magma. Folding and faulting of the strata preceeded the intrusions generally. Originally, the strata of the Wasatch Mountains dipped to the west, but following uplift and folding, they now form, in general, the east dipping limb of an anticline.

LOCATION OF THE AREA AND DESCRIPTION OF THE STRATA

Little Cottonwood Canyon is located about twenty miles southeast of Salt Lake City, Utah. At the head of the canyon, which lies in the northwest corner of T3S, R3E of the Brighton Quadrangle, is the Albion Basin. An Alpine glacier of Quaternary age has carved out this amphitheater-like area. The eastern portion of the area has exposures of Cambrian sedimentary rocks that have been metamorphosed by a pluton of Cretaceous or Tertiary age. Five, possibly six, faults that trend east-west cut the metamorphosed Cambrian beds. The Cambrian Beds show displacement of only about 15 to 20 feet along most faults, but up to several tens of feet in others. At the same time that this placement occured younger rocks of Devonian age have been thrust up across the Cambrian rocks farther to the east in the area. Vegetation and Quaternary sediment cover many of the contacts and they are also difficult to follow because of faulting.

The Cambrian rocks exposed in this area represent over 400 feet of sediment. On the average, these beds strike N25°W and dip 22°E. Slight variations occur across the faults. The greatest deviation appears in a block at the south end of the area where the rocks strike N10°W but dip 22° still. The Cambrian rocks consist of three units each of a different lithology. The lowest stratigraphically is the Tintic Quartzite. This is a formation that consists of a rather homogeneous sequence of medium to coarsed-grained recrystallized quartz that is stained with iron oxides. Weathered surfaces have an orange hue and iron oxides coat bedding planes, fractures and joint faces. Samples #9 and #12 are representative of the rock present. One Sample, #9, has unevenly distributed rusty to yellow-orange looking pits or pockets of iron oxide of about ¼ of an inch in diameter on a fresh surface. Clear quartz and very minor amounts of purplish quartz are revealed on the fresh surface too. About 80 stratigraphic feet are exposed here.

The Ophir Shale lies conformably on the Tintic Quartzite. It consists of three members of which the lowest and uppermost members are metamorphosed pelitic sediment in the north and east portion of the area. To the south, unmetamorphosed sediment is exposed, but here only the middle member, a limestone and the upper member, a shale, are exposed. The limestone member is a fine-grained blue-green limestone. (Sample #1) It has darker, brownish-green siliceous laminae running through it. Fractures within the rock are coated with iron oxide. Weathered surfaces tend to be soft and friable with a brown color. This member is transitional in its upper part with siliceous laminae alternating with limy shales up into the shale of the third member. Where exposed at the south end of the area, this member is represented by approximately 35 feet of strata. Towards the contact, this member forms a slope surface, covered by soil and vegetation. The third member of the Ophir Shale is a bedded shale with variable colors. In general, it is a dull-yellow-brown to gray-green on its weathered surface. It has rather slabby fracture along the bedding and has a calcareous cement. About 120 feet of this member are exposed. To the north where it has been thermally metamorphosed the beds are darker, are recrystallized and have a blocky fracture. Outcrops protrude through the surface cover and form small blocky cliffs. The first member of the Ophir Shale, which is exposed only as metamorphosed rock in the northern parts of the area mapped, resembles the third member very much. Near the contact all members are cut by veins of quartz and igneous material from the intrusion.

The Maxfield Limestone comprises both limestone and dolomite and is conformable on the Ophir Shale. At the south end of the area it is represented by interbedded gray and white dolomite and limestone. They are moderately resistant and may form low but distinct steps in gullies. Sample #3 is a gray to white limestone with a fine-grained granular texture. Small elongate needle-like structures are present which may be fossil remains. Small concentrations of iron oxides and greenish areas of serpentine are found. It has been recrystallized to a marble to the north where this Maxfield Limestone is metamorphosed.

The source of heat for this thermal metamorphism is at the north end of the mapped area. It is a granodiorite known as the Alta Stock. Its east-west dimensions are about three miles and its north-south dimension is about one and a quarter miles wide. Only a small part of it is shown on the map. Its texture varies from equigrained to porphyritic. The rock (Sample #14) is predominantyly composed of idioblastic zoned oligoclase feldspars. Some show Albite-Carlsbad twinning. Biolite forms euhedral, hexagonal, tabular, phenocrysts about 2 to 3 mm across. Euhedral phenocrysts of hornblende about 2 mm long are also present in the granodiorite. Quartz fills the interstices. The feldspars show alteration to sericite. Some sphene, epidote and hematite are also present.

THE EFFECTS OF METAMORPHISM

The release of thermal energy from an intrusive body normally causes metamorphism of the surrounding country rock. The areal extent of metamorphism, or the contact aureole, is regulated by many factors, the most important of which is the size of the intrusion. The size of the aureole is proportional to the size of the intrusion. Some of the changes found in an aureole may be subtle. Changes may not occur as soon in one lithology as in another. There may be little outward sign of changes that can be seen in thin section. In general, though, the rocks tend to become harder, fracture differently, undergo recrystallization to higher grade minerals, and volatiles introduced into the rocks may cause crystallization of minerals not customarily developed in metamorphosed rocks of the given compositions.

Because there were no mappable unmetamorphosed Tintic Quartzite beds in the area, the description of this formation given by Calkans (1943) will be used as a basis for comparison with the metamorphosed quartzite. He describes the Tintic Quartzite as coarse to medium grained quartz-rich sandstones. The bedding is set off by iron oxides. The lower portion consists of some conglomerate near the base and purple quartz derived from Precambrian quartzite. There is some cross bedding in parts. The upper beds are composed of white quartz grains. The rock has a tan to orange weathered surface and iron oxides emphasize bedding and joint faces. Some portions of the formation have quarter-inch diameter rust colored pits, and other parts have distinct porosity.

The quartzite mapped in the area, as represented by Samples #9 and #12, shows no outward changes. The weathered surfaces are still orange colored. Iron oxides still coat fractures and joints. Porosity of some of the original rock has been retained (Sample #9) and the pockets of iron oxides still remain. The only physical, visible changes are an increased hardness and a new fracture across the grains instead of around them. This is due to recrystallization of the quartz to interlocking grains, as seen in thin-section. Small tourmaline and pyrite crystals also are present. Toward the contact the quartzite consists of recrystallized quartz and orthoclase. Since the samples were not taken from the same bed, grain sizes may not be compared. Because an important part of the quartzite is covered, the relation between metamorphic aureole size and intrusive body size cannot be established.

In the metamorphosed Ophir Shale, a darker color than in the original rock is exhibited. It becomes harder and bedding disappears. A blocky fracture is developed. Iron oxides are still present along fractures and weathered surfaces. The grain size increases slightly toward the contact. In thin section, the original rock consisted of quartz and oligoclase in subangular grains, calcite, muscovite and possibly some actinolite and pyrite were present (Sample #2). In Sample #4, at about 2,200 feet from the contact, epidote is crystallized in the matrix of quartz, plagioclase and sericite. The granoblastic texture and presence of epidote are the first definite signs of thermal effects. This area will be taken as the outer limit of the aureole in the Ophir Shale. This rock also contained pyrite and iron oxide staining. Sample #6 again has aggregates of epidote with quartz. In thin section, tourmaline is present, which may be detrital or recrystallized from even more minute detrital material. They may also be the product of metasomatism. Microscopically, Sample #8 shows that the quartz has been recrystallized, biotite and muscovite are present in larger grains and cordierite has crystallized. Cordierite is missing in the next sample (Sample #11) which was taken at approximately 400 feet from the contact. Orthoclase is now present and muscovite is present in both large and small flakes. The presence of chlorite suggests some retrograde metamorphism. Sample #13 taken at only 100 feet from the contact shows no change in mineral composition compared with Sample #8. The effects of thermal energy on this shale were the recrystallization of the original components to form higher grade minerals, the development of a hornfelsic texture, and disappearance of bedding structure. As a result of recrystallization, the rock was hardened.

In the Maxfield Limestone, the first effects of thermal energy are seen as recrystallization of granular calcite to calcite showing cleavage and having a larger grain size. There is little change in color, though some are very white whereas some are yellowish. The original sample (Sample #3) had what appeared to be fossils in it, whereas the metamorphosed limestone has none. Sample #5 taken in the Maxfield Limestone about 1,800 feet from the contact, first shows mineralogical changes. Diopside has crystallized in recrystallized calcite. Serpentine is also found. This area in which diopside is first found will be taken as the limit of the metamorphic aureole in the Maxfield Limestone. However, limestones and dolomites are relatively susceptible to metamorphism and, therefore, the limit of the aureole proably extends at least as far south as it does in the Ophir Shale. The next sample (#7) was taken closer to the contact. It had a purer composition originally and contains only recrystallized calcite with some hematite. At about 400 feet from the contact Sample #10a of the marble shows the crystallization of forsterite and a mineral from the humite group. The forsterite has bleb crystal form and the possible humite group mineral has euhedral form. Another new mineral, ludwigite, is also present. Ludwigite is a rather rare borate mineral. It is unlikely to have been an orginal constituent of the limestone. Sample #10b was taken at about 200 feet from the contact and 4 feet from the vein from which sample #10c was taken. Sample #10b still has the forsterite, but it is now partially pseudomorphed by serpentine. The calcite cleavage is less distinct. Euhedral to subhedral grains of sphene are also present. There has been no further change in mineralogy then since sample #10a. The marbles of the metamorphosed Maxfield Limestone contain new minerals, diopside and forsterite, in matrices of recrystallized calcite. The color of the rock varies little and there is an increase in coarseness of grains.

In all three lithologies new minerals were crystallized from the constituents of the original rock. In general, the closer they were to the contact, the higher the grade of minerals present. The extent of the aureole of metamorphism in both the Ophir Shale and the Maxfield Limestone was about 2,200 feet from the contact. From the size of the aureole and highest grade of minerals present, the size of the intrusion near the area mapped is relatively small and temperatures were relatively low.

ESTABLISHING HORNFELS FACIES FOR THE THREE LITHOLOGIES

In metamorphism minerals recrystallize in steps from lower grade minerals to high grade minerals. Each step may be represented by certain mineral assemblages that can coexist at equilibrium under particular physical conditions. As the physical conditions are altered and the limits of equilibrium are surpassed, new minerals will crystallize.

Since there are different types of rocks, for example, limestones, quartzites, shales, etc., each rock has a different mineral and chemical composition. Thus new assemblages of minerals that crystallize during metamorphism are dependent upon the composition of the uninfluenced rock. Because minerals recrystallize in steps that depend on physical conditions, a particular assemblage of minerals may be correlated to each step or set of physical conditions and each rock type. Each assemblage of minerals is called a facies. Each facies is categorized by textures that occur as a result of thermal metamorphism or regional metamorphism (i.e., the Hornfels facies for thermally metamorphosed rocks; the Schist facies for regionally metamorphosed rocks.) Each texture is then further described by mineral names of minerals that occur under the physical conditions present for each step of crystalization (i.e., Albite-Epidote Hornfel facies or the Green-schist facies.) The Albite-epidote hornfels facies is the term used for minerals that develop at about 400° C and at very low pressures. This facies includes the minerals epidote, albite, tremolite, chlorite, pyrophyllite, muscovite, calcite and quartz. The next facies, the Hornblende hornfels facies, has a temperature range from about 510° C to 550° C under pressures of 500 to 2,000 bars. Under these conditions an-rich plagioclase, garnet, diopside, hornblende, cordierite, andalusite or muscovite and andalusite may crystallize depending upon the original chemical composition of the rock. The highest grade hornfels facies is the K-feldspar-cordierite hornfels facies. Its temperature range is from 580° C to 640° C with pressures between 500 and 2,000 bars. (Winkler 1967) This last hornfels may be divided into subfacies if it is necessary. In this facies an-rich plagioclase or garnet, diopside, enstatite/hypersthene, andalusite/sillimanite, orthoclase and andalusite or wollastonite may occur depending on the original chemical composition. Forsterite may occur in rocks having no quartz and represents either the Hornblende hornfels facies or the K-feldspar-cordierite-hornfels facies.

In the metamorphosed quartzite it appears that near the contact where orthoclase is present in the quartzite, conditions may have existed which were favorable for the K-feldspar-cordierite hornfels. The orthoclase might be detrital. The bed containing orthoclase would have to be traced away from the contact to see whether or not it is detrital. This area containing orthoclase extends about 600 feet from the contact. South of that boundary orthoclase was not present nor were cordierite or andalusite or minerals characteristic of the Hornblende-hornfels facies. This may mean that the chemical composition was not favorable for that facies. But because the quartzite is recrystallized indicating that it was effected by the heat, at least two facies are represented in the quartzite.

The metamorphosed Ophir Shale exhibits a similar trend that can be followed. Within 600 feet of the contact, orthoclase is present and may be detrital or a remnant of the K-feldspar-cordierite-hornfels facies that has undergone retrograde metamorphism. The presence of chlorite in samples 11 and 13 suggests that retrograde metamorphism has occured. Where Sample #8 was collected at about 1,200 feet from the contact, cordierite made its first appearance in the presence of muscovite. This combination is diagnostic of the hornblende-hornfels facies. Another 400 feet south, 1,600 feet from the contact there is no cordierite. Epidote is prevalent here though, so the albite -epidote-hornfels is represented. Thus, the Ophir Shale has the two lowest grade hornfels facies present with the highest grade hornfels as a remnant near the contact that has undergone retrograde metamorphism.

At 200 feet and 400 feet from the contact forsterite is present in the metamorphosed Maxfield Limestone. Forsterite is a mineral that occurs in rocks without quartz. It can also be found in both the Hornblende-hornfels facies and the K-feldspar-cordierite-hornfels facies. This presents a problem, for if there is a facies boundary in the vicinity, it can not be distinguished. To the south a sample of the marble (Sample #5) has diopside present. Diopside is found in the Hornblende-hornfels facies. For the metamorphosed Maxfield Limestone there are probably all three facies present. Since limstones are quite susceptible to metamorphism and because the Ophir Shale exhibits all three facies, the Maxfield Limestone probably does too. Because of the lack of samples and lack of diagnostic minerals present, however the boundaries for the facies could not be determined.

METASOMATISM

Present in the various lithologies are minerals that are not likely to occur in metamorphosed rocks such as the three lithologies being studied. This suggests introduction of elements that would change the bulk composition of the rock and allow the formation of these minerals. The replacement of or addition to the existing rock composition is called metasomatism. It is brought about by the flow of magmatic volatiles charged with active elements through the surrounding country rock. In the Maxfield Limestone near the contact the mineral ludwigite (Samples #10a and 10b) is found. This mineral is a borate, which suggests that boron was introduced into the marble by volatiles from the granodiorite. Tourmaline, a boron silicate, might also have developed in this manner, but because of its small size, it is probable that it is a detrital mineral. Sulfides (i.e., pyrite) and iron oxides (i.e., magnetite and hematite) could also have been the result of this process, but their small grain size and widespread occurrence suggests that they are not metasomatic.

CONCLUSION

From the results of this study it may be suggested that, in this case, the extent of the effects of metamorphism was similar in each lithology. The limit of the aureole of metamorphism in the limestone and shale coincided. closely. The aureole extended about 2,200 feet from the contact. This is a relatively short distance and might suggest that the intrusion in this area is small, perhaps a mile wide or less. In general the rocks become harder and exhibit recrystallization. Higher grade minerals that are characteristic of the particular hornfels facies for contact metamorphism are crystallized. The various grades of minerals present show that all three hornfels facies are present. The three facies in each lithology seem to correspond with those of the other lithologies. Their various widths are dependent upon the size of the size of the intrusive. There has been some metasomatism near the contact, but only the ludwigite is a definite result of metasomatism, the borate ion probably being the introduced element.

APPENDIX

The following are megascopic and microscopic descriptions for samples taken from Albion Basin at the head of the Little Cottonwood Canyon, Alta, Utah.

SAMPLE #1

Sample #1 is a fine-grained bluish-green to gray limestone. There are silicone laminae of darker brownish color running through the sample. Cracks tend to be emphasized by a dark brown mineral coating of iron oxide. Weathered surfaces have a softer texture than fresh surfaces and it is brown in color.

In thin section the rock is very fine grained calcite. Small lenticular pockets of calcite having distinct rhomb form can be found. Bits of hematite are present and iron oxide stain is prevalent along cracks.

Mineralogy

Calcite - very high birefringence  rhombohedral form in pockets.

Hematite - brown to opaque staining along cracks

SAMPLE #2

Megascopically, Sample #2 is a fine-grained greenish-gray shale that effervesces in dilute HCl. It weathers to a brownish gray. The rock is predominantly quartz. Some surfaces have grains of calcite visible on them. Streaks of brownish orange color on surfaces and on the interior may be due to the alteration of iron oxides. The fresh surface has a sugary appearance.

Microscopically, Sample #2 is a fine-grained calcareous shale having sub-angular quartz forming about 45% of the rock. Granular calcite is somewhat uniformly dispersed among the quartz grains and forms about 20% of the rock. There is a small amount of plagioclase grains of oligoclase composition in the rock. They are angular and are uniformly distributed through the rock. The remainder of the rock is formed by muscovite.

Minerology

Quartz - subangular grains form about 45% of the rock.

Plagioclase - angular grains having Albite-Carlsbad twinning grains are same size as those of quartz grains. They are of oligoclase composition. They form less than 7% of the rock.

Calcite - granular calcite; some grains give uniaxial negative optic figure. The grains have very high birefringence and are also about the same size as the quartz grains. It forms about 20% of the rock.

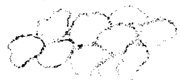
Muscovite - pale green columnar grains and some fibrous grains having distinct relief above the rest of the rock constituents, are moderately birefringent and form about 20% of the rock.

Hematite - occurs as stain.

SAMPLE #3

Sample #3 is a white to gray granular limestone. Elongate fragments which may be fossils are randomly dispersed in the rock. Iron oxide is present along fractures and sometimes in pockets. Small crystals of a dark mineral are scattered through the rock.

In thin section granular calcite makes up about 80% of the rock. It is fine-grained and the calcite has the characteristic uniaxial negative optic property, but it shows no rhombohedral cleavage. Porphyroblastic pyrite altering to hematite is also found. Elongate or lenticular sections that may be of calcite composition may be fossil remnants.

Calcite - uniaxial negative;  granular form; fine-grained with some areas a little coarser than bulk of the rock. They form 80% of the rock.

Pyrite - opaque; yellow in reflected light; altering to hematite.

Hematite - lateration of pyrite and thus pseudomorphing pyrite.

SAMPLE #4

Sample #4 is a fine-grained Quartz-Epidote-Hornfels. Weathered surfaces are green-brown. A fresh surface reveals a green-gray color. Micas are detectable as small cleavage flakes of less than 1 mm in size. Quartz is the major constituent of the sample. The greenish tint is probably due to the coloration of a green mineral such as chlorite or epidote. Pyrite altering to hematite is also present.

In thin section, sample #4 is found to be a Quartz-Epidote-Hornfels. The major constituents, quartz and epidote, impart a granoblastic texture. Quartz forms about 50% of the rock, epidote about 20%. Epidote is present in grains about 1/8 the size of the quartz grains and also in aggregates. Plagioclase having a grain size equivalent to the quartz grains is present as very small amounts. Flakes of sericite and some larger of muscovite are scattered through the sample. Small amounts of sphene enclosing opaques are also found. Minor amounts of pyrite are present also.

Quartz - 50-60% of rock.

Plagioclase - Less than 2% of the rock twinned grains.

Epidote - high relief, high birefringence, Parallel extinction; aggregates of grains.

Muscovite - highly birefringent, upper 2nd to 3rd order colors; forms less than 5% of rock.

Sericite - fine fibrous aggregates

Pyrite - yellow in freflected light is altering to hematite.

Hematite - staining along cracks is brownish alteration product of pyrite.

SAMPLE #5

Sample #5 is medium-grained Diopside Marble. The major constituent of the sample is calcite, showing good cleavage surfaces. Short prismatic grains of diopside are scattered through the calcite. Small individual pockets and a few veinlets of waxy blue-gray mineral may be serpentine. Iron oxide stains fractures and appears in scattered pockets.

Microscopically, sample #5 is a Diopside Marble. Calcite forms straight-sided interlocking grains that shows twinning. The strained grains have parallel high birefringent bands across cleavage rhombohedra. Diopside may form prismatic grains having well formed straight edges. One aggregate of grains forms radiating blades from a prismatic cross-section. It exhibits typical pyroxene cleavage and some parting. Serpentine forms irregular aggregates at calcite grain triple points. Hematite can be found as an alteration of pyrite crystals.

Diopside - has high relief of 1.65 - 1.7 I. R. Is optically positive and biaxial; has a birefringence of .014 - .025; is colorless in prismatic grains and has typical pyroxene cleavage

Calcite - recrystallized to form grains showing rhombohedral cleavage.

Serpentine - low birefringence and low relief; fibrous anhedral grains form irregular aggregates at calcite grain triple points.

Hematite - forms aggregates and single grains; small percent present.

Pyrite - is yellow in reflected light; very small amount is present.

SAMPLE #6

Megascopically, Sample #6 is a Quartz-Mica-Hornfels having a very fine grained texture and dark gray color. Weathered surfaces are dark gray-green. It has a blocky fracture and is hard. Cleavage surfaces of micas can be seen in some cases in the rock and on fractured planes. Hematite stains fracture planes or veinlets.

Microscopically, Sample #6 is a Quartz-Epidote-Mica-Hornfels. Quartz appears as subangular grains forming much of the rock. Strongly birefringent shreds and occasional flakes of sericite-muscovite form a matrix. Epidote also forms small aggregates of yellow-green grains having high birefringence. Iron oxides have prominent staining effect along fractures and some areas of stain are disseminated into the unfractured whole rock. Minor amounts of prismatic blue-green tourmaline are also randomly scattered through the rock.

<u>Quartz</u> - is uniaxial positive, has low relief, low birefringence of .009. Forms about 30% of the rock as sub-angular grains.

<u>Epidote</u> - aggregates of yellow-green grains having high birefringence of upper 2nd order to 3rd order colors. Also has high relief.

<u>Tourmaline</u> - small prismatic grains of blue-green color exhibit east-west darkest color for pleochroism.

<u>Sericite</u> - fine shreds of white mica having moderate relief and moderate to high birefringence.

SAMPLE #7

Sample #7 is a coarse-grained light gray to yellow-brown Marble. The grains are poorly cemented and the rock crumbles easily. This may be due to solution of the cement. A brownish stain may be due to weathering of hematite. Solution of some of the calcite or iron oxides have caused nearly linear type veinlets.

Microscopically, Sample #7 is over 95% calcite. The grains have distinct cleavage and straight edges. They also show polysynthetic twinning. Grains of hematite pseudomorph pyrite with cores of pyrite still remaining at the center of the grains of hematite.

Calcite - forms about 95% or more of rock. Grains are straight sided and show cleavage; also show polysynthetic twinning.

Hematite - pseudomorphs pyrite and is brown to opaque.

SAMPLE #8

Megascopically, Sample #8 is a fine-grained gray-green Quartz-Mica-Hornfels. Weathered surfaces are dark brown-green. Flakes of mica are present on fracture surfaces, weathered surfaces and on fresh surfaces. The dark color of the weathered surfaces may be due to iron oxides.

In thin section, Sample #8 is a fine-grained Quartz-Mica-Cordierite-Hornfels. Recrystallized quartz has formed interlocking grains. Quartz also forms inclusions in anhedral grains of cordierite. The cordierite also shows some alteration to sericite. Muscovite is present in fibrous aggregates as well as in flakes. Biotite in small flakes and some tiny cross sections is found in small aggregates. Columnar, elongate grains of clinozoisite having anomalous blue birefringence are scattered among the cordierite dominated areas. Small amounts of prismatic tourmaline also are present. Pyrite in cubic form and black magnetite are found with alteration to hematite.

Quartz - fine interlocking grains having wavy extinction and as inclusion in cordierite.

Cordierite - anhedral irregular sided grains  having low relief and low birefringence; resembles quartz but is biaxial negative. Optic figures are difficult to obtain. Has many inclusions.

Biotite - small green columnar and subeuhedral cross-sections. Columnar grains have high birefringence, cross-sections, low.

Muscovite - has moderate relief, moderate to high birefringence, forms fibrous to columnar grains of variable size, but in general all small.

SAMPLE #8 (Continued)

Tourmaline - prismatic green grains having east-west darkest color pleochroism. It is probably of sedimentary origin.

Clinozoisite - has low birefringence blue-gray color, high relief 1.7; prismatic grains not well formed. Some show parting.

Pyrite - yellow in reflected light; opaque in plane light; cubic form.

Hematite - alteration of pyrite.

SAMPLE #9

Sample #9 is a medium grained Quartzite. A weathered surface is yellow-orange as well as green-black along fractures exposed to weathering. A fresh surface reveals clear quartz with some very minor amounts of blue quartz. There are also some quarter inch pockets of orange stained quartz. Some pockets have an iron oxide at the center. Where these oxides have been removed, the quartz appears to be porous.

Microscopically, this sample is an orthoquartzite. Recrystalized quartz forms irregular interlocking grains. Some grains show some stress for their optic figures are biaxial with small 2V's. Some muscovite and sericite fill small interstitial pockets. Some tourmaline is present and hematite pseudomorphs pyrite.

Quartz - anhedral grains with  irregular interlocking edges; is fine to medium grained; has wavy extinction and makes up about 90-95% of the rock.

Sericite-muscovite - fine fibers fill interstices; some is pale green to clear.

Tourmaline - pleochroism typical to tourmaline is present.

SAMPLE #10a

Megascopically, Sample #10a is a medium to fine-grained buff to gray Marble. The recrystallized calcite shows distinct rhombohedral cleavage. A black mineral having short prismatic to needle like grain form is present in concentrations while nearly absent in other portions. The mineral has a rhombohedral cross section and some striations lengthwise on the crystal grains. They have an adamantine luster. It is probably the Ludwigite which is common to the area. Forsterite resembles an off color or cloudy quartz and is diseminated through the rock and also forms small veinlets across the rock.

Microscopically, Sample #10a is a medium grained Forsterite Marble. Calcite forms a matrix of subhedral twinned grains. Forsterite is in bleb form having high birefringence and showing some parting. It has a large biaxial 2V and many grains have an optic figure looking down one of the optic axes. It is optically positive. Small yellow-green subhedral grains of a mineral from the Humite group are present. Very dark to green euhedral rhombohedral cross sections of ludwigite are scattered through the rock. Columnar sections are also seen. It is a pleochroic green to dark brown mineral having high relief and variable biaxial 2V's. Subhedral rhombs of sphene are associated with the ludwigite.

Calcite - low relief which varies to very high as stage is rotated; irregular grains having rhombohedral cleavage and have uniaxial negative figures.

Forsterite - bleb-like grains having 3rd order colors of birefringence, high relief, biaxial positive figures with large 2V's may be found.

SAMPLE #10a (Continued)

Unknown - euhedral to subhedral hexagonal grains having very high birefringence and high relief. Optic figures are not good but appear to be nearly uniaxial with a negative optic sign.

Ludwigite - deep green to nearly black mineral. Pleochroic from green to brownish green. Rhombohedral cross sections show parting.

Prismatic grains are otherwise formed

Cross sections appear to have biaxial figure with variable 2V's and the birefringence is masked by color of mineral. It has high relief of about 1.7 I.R.

SAMPLE #10b

Sample #10b is a creamy white Marble that weathers to a pitted buff colored surface. Tiny inclusions of ludwigite are present in 1 mm grains. The calcite present is of anhedral grains showing good cleavage.

In thin section sample #10b is a Forsterite Marble having serpentine pseudomorphs of the forsterite. The serpentine is fibrous, has low birefringence and has the bleb form of the forsterite. Ludwigite again appears in the rhombohedral cross section, is pleochroic green to brown. Sphene is present in subhedral rhombs and in these is some magnetite in subhedral form. The calcite is not clear, but is hazy brown to gray. Some show no cleavage.

Calcite - irregular grains cut by bleb-like structures of forsterite and serpentine. Rhombohedral cleavage is present and in some places has been partially destroyed. The grains show very high birefringence. An optic figure can be obtained on a few grains. It forms about 45-50% of the rock.

Forsterite - bleb-like structures show parting and have high relief and high birefringence. It forms about 10% of the rock.

Serpentine - Fibrous serpentine Pseudomorphs the bleb-like forsterite. It has low birefringence and low relief. The replacements form about 30% of the rock.

Ludwigite - It is present in accessory amounts, shows its green to brown pleochroism, but it is not well formed.

Sphene - Subhedral grains surround magnetite.

Magnetite - opaque mineral surrounded by magnetite.

SAMPLE #10c

Sample #10c is a Diorite vein intruding limestone that has been marblized. It is formed of medium-grained plagioclase and a pyroxene. The rock has an overall gray color with uniform distribution of the dark pyroxene mineral. Plagioclase has good cleavage faces on a fresh surface and on a weathered surface they are clouded.

Microscopically sample #10c is a Diorite. It has medium-grained plagioclase of andesine composition making up nearly 70% of the rock. Hedenbergite, an iron rich pyroxene, forms euhedral to subhedral cross-sections and prismatic grains. 20% of the rock is hedenbergite. Grains of antiperthite are present and have little or no distinct grain form. The antperthite grains are twinned however. Accessory amounts of quartz, sphene, and clinozoisite and magnetite form the remainder of the rock.

Mineralogy

Hedenbergite - It forms about 20% of the rock. It has a biaxial positive figure with a moderate to large 2V, is slightly pleochroic, has low birefringence, and is brown to green. With nicols crossed it extinguishes at 44 to 50 degrees.

Plagioclase - forms 70% of the rock and is twinned; it has the composition of andesine. A prominent part of the plagioclase has undergone some segregation and antiperthite has been formed. These irregular grains are also twinned.

Quartz - Less than 5% of the rock is quartz that fills some interstices.

Sphene - Grains are subhedral rhombs that are red-brown; very high birefringence is masked by its color and it has high relief; it is often associated with or surrounds magnetite.

SAMPLE #10c (Continued)

Clinozoisite - Accessory amounts of prismatic grains have anomalous birefringence and high relief with parallel extinction. It occurs as inclusions in other minerals or alone in small interstices.

Magnetite - opaque mineral surrounded by sphene

SAMPLE #11

Megascopically sample #11 is a fine-grained Quartz- Mica-Chlorite Hornfels. Flakes of mica are found on fresh surfaces as well as chlorite and quartz. The weathered surface is dark green-brown with some reddish areas. These colors are due to the weathering of the chlorite and iron oxides.

Microscopically sample #11 is a Quartz- Mica- Chlorite Hornfels. Quartz and muscovite form about 60% of he rock in equal proportions. Chlorite forms about 20% of the rock and seems to occur along quartz-muscovite grain contacts. A few clear grains are present which have low relief and low birefringence and are biaxial negative with a large 2V. They may be grains of orthoclase. The chlorite represents retrograde metamorphism. The minor amounts of orthoclase that are present may also be due to retrograde metamorphism.

Mineralogy

Quartz - It is uniaxial positive, has the normal relief and low birefringence and has wavy extinction. It forms 30% of the rock.

Muscovite - It is pale green to clear and occurs as fibrous grains with moderate birefringence. A few grains are columnar. It forms 30% of the rock.

Chlorite - It occurs as pale green to green fibrous grains that have low birefringence. They are found along muscovite and quartz grain contact areas. It forms 20% of the rock.

Orthoclase - It is found as polygonal grains but because there is so little of it, it is difficult to find. They have the biaxial negative figure with a large 2V that is often not centered.

Hematite - Small opaque grains uniformly scattered through the rock.

SAMPLE #12

Sample #12 is a Quartzite that is orange stained on the weathered surfaces. Iron oxides emphasize fractures with dark brown on surfaces exposed to weathering. On fresh surfaces, the fractures are orange-yellow. Clear quartz and a smaller amount of white feldspar form the bulk of the rock.

Microscopically, sample #12 is a K-feldspar Quartzite. Quartz in in irregular grains that exhibit strain effects, i.e. it has a biaxial optic figure with a small 2V. Orthoclase is intergrown in the quartz matrix. It is clouded by alteration to sericite. Muscovite in fibrous form may occur in interstices or in pocket-like circular aggregates. Hematite is also present.

Mineralogy

Quartz - It occurs as irregular interlocking grains having typical optic properties of quartz. Some grains have been strained and now have a biaxial optic figure with a small 2V. Quartz forms about 80% of the rock.

Muscovite - It is moderately birefringent, in fibrous grains occurring in less than 5% of the rock. A few circular pockets of the fibrous mineral may be found.

Orthoclase - The grains conform to the grain boundaries of the quartz. They have alterations to sericite. They are usually smaller than the quartz grains. Because of the alteration, they are distinguished in plane light from the quartz areas.

SAMPLE #14

Sample #14 is a porphyritic Granodiorite. Phenocrysts of tabular, hexagonal biotite about 2-3mm across and hornblende phenocrysts about 2mm long are imbedded in a matrix of prismatic grains of feldspars. Quartz is present in interstices. Weathering has dulled the luster of all exposed mineral surfaces.

In thin section sample #14 is a coarse-grained porphyritic Granodiorite. Hornblende is present in typical amphibole form. Plagioclase of andesine composition occurs in euhedral grains that show alteration to sericite. Sphene is present in subhedral grains. Biotite is present in typical form. Accessory amounts of magnetite, hematite and epidote are present.

Mineralogy

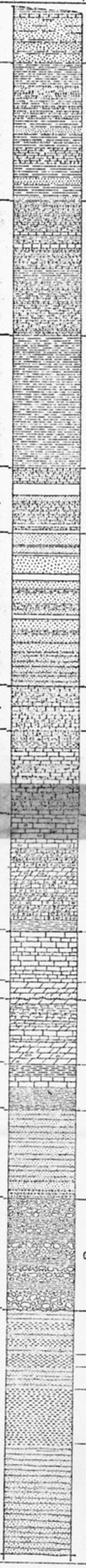
Plagioclase - has Albite-Carlsbad twinning and composition of oligoclase. Coarse grained. Some grains show euhedral growth zones. A few show both twinning and zoning. Many are severely altered to sericite.

Hornblende - poorly formed columnar sections of light blue-green pleochroism is present. They are biaxial negative and have an extinction angle of about 12°. A few subhedral cross-sections are present and show typical amphibole cleavage. They are biaxial and have a large 2V.

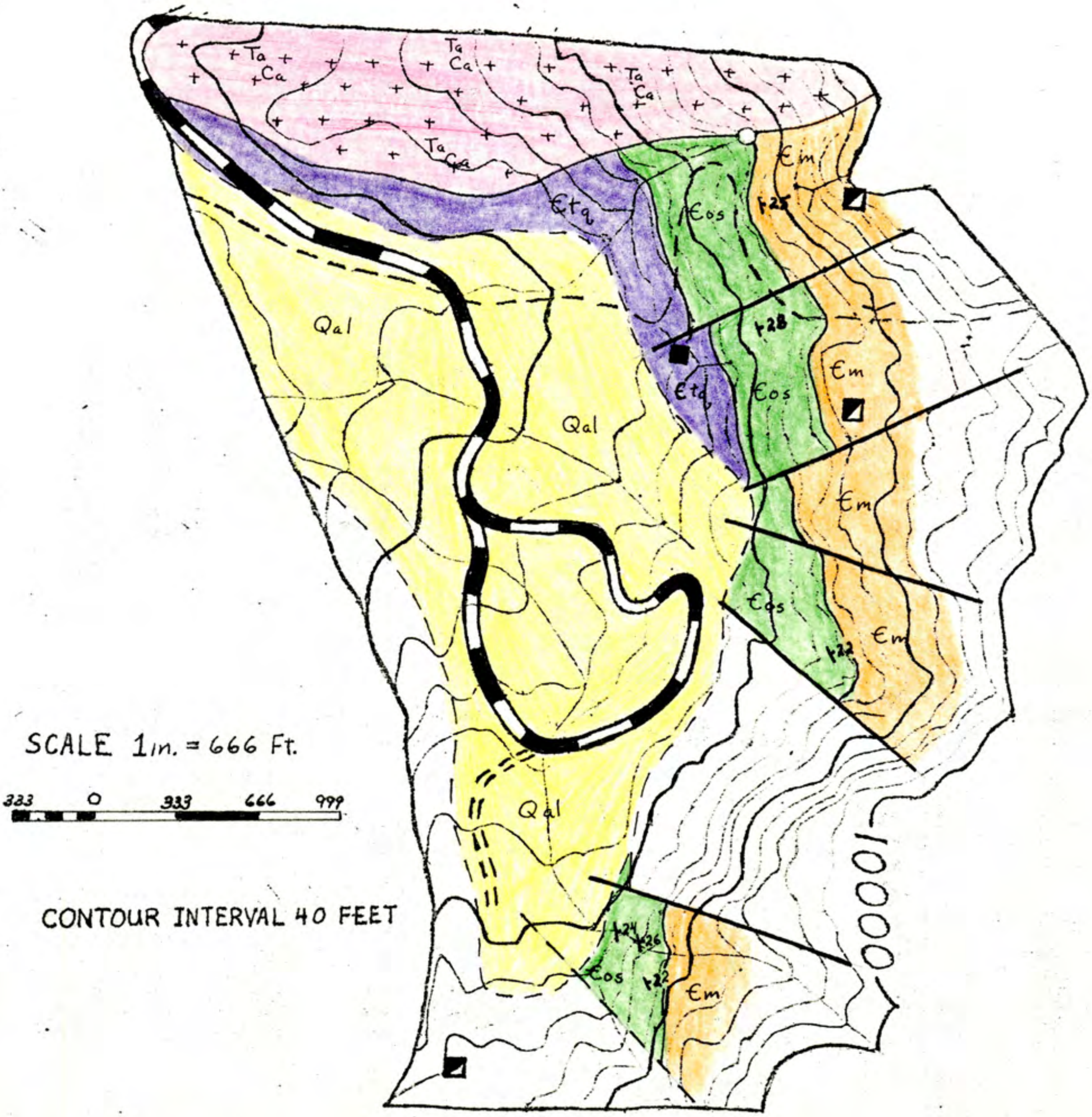
Biotite - columnar grains having parallel extinction.

Sphene - red-brown, very highly birefringent, but marked by color; associated with magnetite.

Magnetite - euhedral opaque black grains.

System	Series		Formation	Section	Thickness (feet)	Kind of rock
Jurassic.		Jn	Nugget sandstone.			Light-colored sandstone with interbedded red shale.
Triassic(?)		Ŧa	Ankareh shale.		1,225	Red shale, locally sandy, with interbedded coarse gray sandstones. Prominent bed of light-colored hard sandstone near the middle.
Triassic.		Ŧt	Thaynes formation.		1,180	Limestone with sandstone and shale, the calcareous rocks weathering brown in part. A stratum of red shale separates a more calcareous upper portion from a more sandy lower portion.
Triassic.		Ŧw	Woodside shale.		1,175	Shale, mainly red, partly altered to green; fine-grained, thin-bedded. Ripple marks, mud cracks, and rain-drop imprints.
Carboniferous.	Permian.	Cpc	Park City formation.		575	Limestone with interbedded quartzite, sandstone, and shale and a little phosphate rock.
Carboniferous.	Pennsylvanian.	Cw	Weber quartzite.		1,350+	Fine-grained, homogeneous quartzite, white to pale gray, weathering pale buff, interbedded with calcareous sandstone and with gray limestone which is cherty in part.
Carboniferous.	Pennsylvanian.	Cmo	Morgan(?) formation.		350±	Limestone, gray, cherty. Green nodular shale and red limestone near top. Conglomerate at base, pebbles of chert and limestone.
						— Unconformity —
Carboniferous.	Mississippian.	Ch	Humbug formation.		750±	Limestone, black, cherty; large corals and other fossils near top. Limestone, black, weathering to buff, more or less argillaceous. Black shale, apparently absent in southern part of area. Limestone, gray to buff, interbedded with calcareous shale and sandstone.
Carboniferous.	Mississippian.	Cdm	Deseret limestone.		900	Limestone, dark blue to white, not much chert (300 ft.). Limestone and dolomite, dark, very cherty (250 ft.). Dolomite, whitish, crinoidal, large lumps of pale chert (100 ft.). Dolomite and magnesian limestone, very cherty; black shaly beds at base (300 ft.).
Carboniferous.	Mississippian.	Cdm	Madison limestone.		450	Limestone, partly magnesian, free from chert; blue, altering to blue and white; highly fossiliferous, especially near base.
Devonian (?)		Dj	Jefferson(?) dolomite.		150	Dolomite, mostly thick-bedded; bluish-white bed at top; flaggy and vuggy layers; sandstone at base.
						— Unconformity —
Cambrian.	Upper Cambrian.	Ꞓm	Maxfield limestone.		570	Dolomite, gray, mottled, oolitic (70 ft.). Limestone, gray to buff-mottled, interbedded with shale (150 ft.). Dolomite and limestone, mottled with buff and gray (150 ft.). White dolomite, sandy in upper part (20 ft.). Dolomite, mostly gray, lower part largely oolitic (180 ft.).
Cambrian.	Middle Cambrian.	Ꞓo	Ophir shale.		420	Shale, partly calcareous, greenish gray, yellowish brown on weathered surface. Limestone, nodular and mottled. Dark micaceous shale.
Cambrian.	Lower Cambrian.	Ꞓtq	Tintic quartzite.		800±	Quartzite, light-colored, conglomeratic layers near base.
						— Unconformity —
Cambrian(?)		Ꞓt	Tillite.		0 to 1,000	Tillite interbedded with varved shale; dark-colored, weathering rusty.
						— Unconformity(?) —
Pre-Cambrian.		pre-Ꞓ			400	White quartzite. Light-colored quartzite interbedded with purple shale.
Pre-Cambrian.		pre-Ꞓ			100	Argillite, dark purple with green areas.
Pre-Cambrian.		pre-Ꞓ			200	Rusty purple quartzite.
Pre-Cambrian.		pre-Ꞓ			500	Argillite with slaty cleavage; dark gray, stained with ocher on weathered surface.
Pre-Cambrian.		pre-Ꞓ			1,000+	Mainly quartzite, whitish to red or dull purple; upper beds fine-grained and white.

GENERALIZED STRATIGRAPHIC SECTION OF SEDIMENTARY ROCKS OF COTTONWOOD-AMERICAN FORK AREA.



Quaternary	Qal	Alluvium
Tertiary Cretareous	Ta Ca	Alta Stock
Cambrian	Ꞓm	Maxfield Limestone
Cambrian	Ꞓos	Ophir Shale
Cambrian	Ꞓtq	Tintic Quartzite

Faults

Contacts

Roads

Jeep Trail

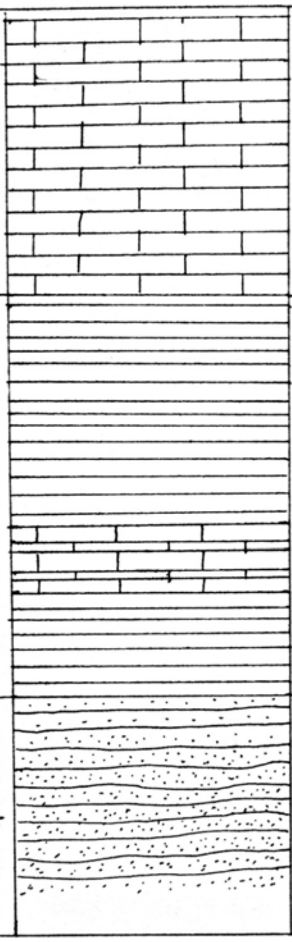
Mine Shafts

TABLE II

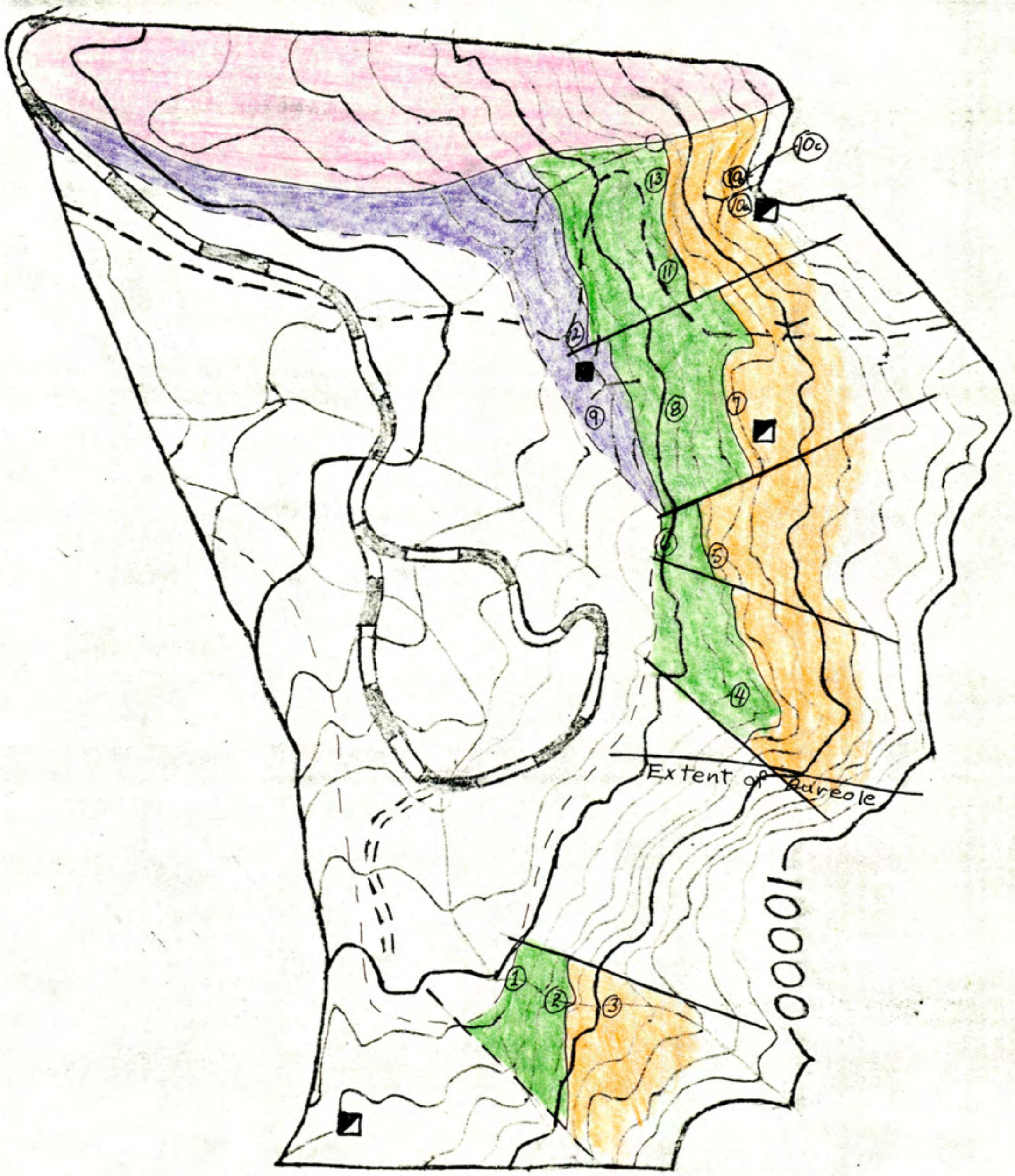
STRATIGRAPHIC SECTION

OF

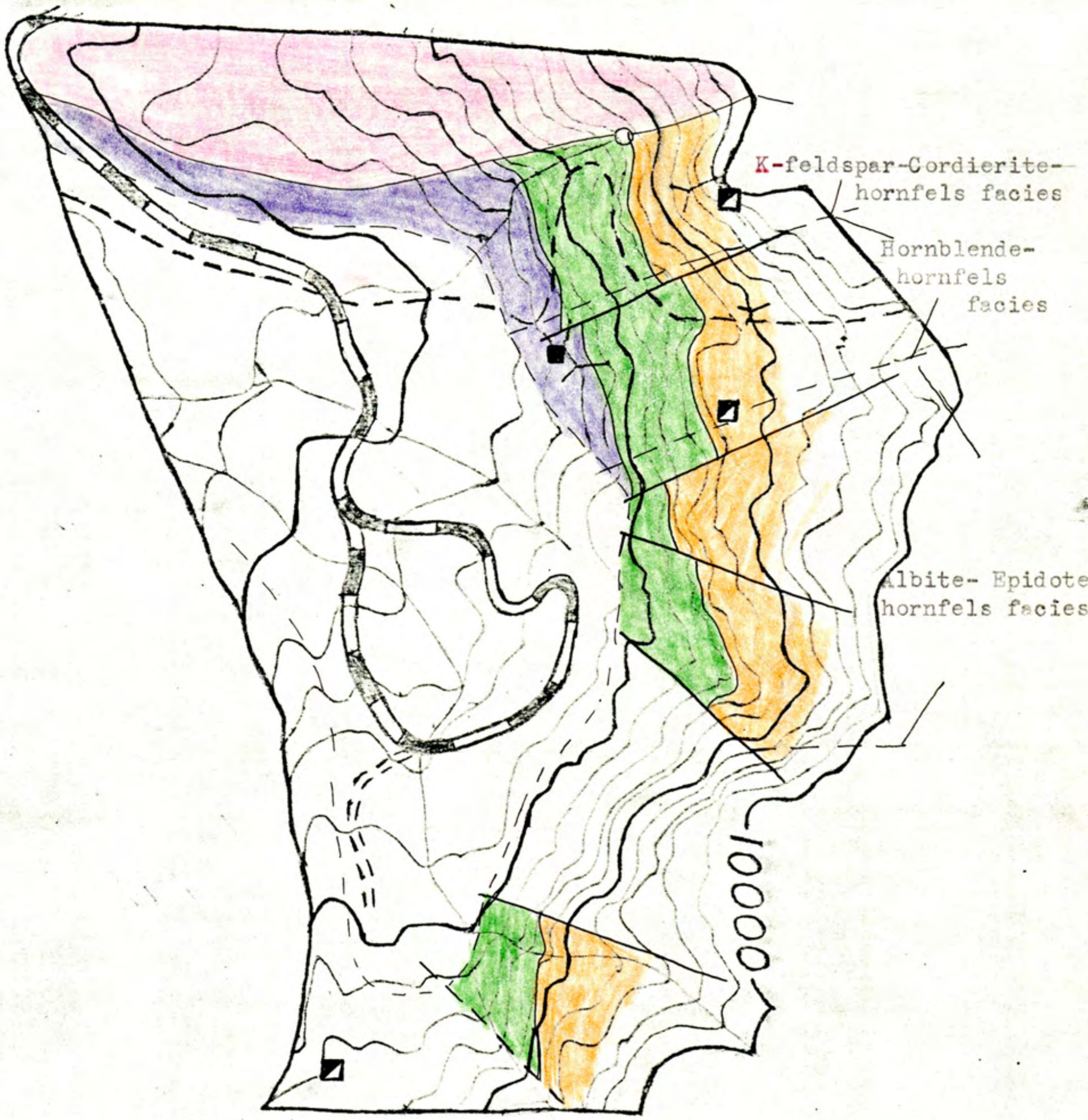
~~AREA~~ AREA MAPPED

CAMBRIAN	Єm	160'+		MAXFIELD LIMESTONE	Interbedded limestone and dolomite. The alternating gray and white beds are moderately resistant. They may fossiliferous.
	Єos	210'		OPHIR SHALE	Bedded shale of variable shades of yellow-brown. Parts are calcareous. It has a slabby fracture along the bedding. Fine grained blue-green limestone. Brown siliceous laminae run through it. Dark micaceous shale.
	Єtq	80'+		TINTIC QUARTZITE	Homogeneous sequence of medium to coarse grained quartz. Iron oxides coat bedding planes. Bulk of the rock is clear quartz. Parts are porous.

All of the rock types have been metamorphosed to marbles, hornfels, and quartzite.



LOCATION OF SAMPLES
AND
EXTENT OF METAMORPHIC AUREOLE



ESTIMATED BOUNDARIES OF METAMORPHIC FACIES